
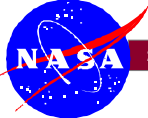


HIGH MISALIGNMENT CARBON SEALS FOR THE FAN DRIVE GEAR SYSTEM TECHNOLOGIES

Dennis Shaughnessy and Lou Dobek
United Technologies—Pratt & Whitney
East Hartford, Connecticut



2005 NASA Seal/Secondary Air Delivery Workshop

High Misalignment Carbon Seals

High Misalignment Carbon Seals

For The

Fan Drive Gear System Technologies

Dennis Shaughnessy / Lou Dobek
United Technologies - Pratt & Whitney
860-557-1675 / 860-565-3034
dennis.shaughnessy@pw.utc.com / louis.dobek@pw.utc.com

November 8-9, 2005

Aircraft engines of the future will require capability bearing compartment seals than found in current engines. Geared systems driving the fan will be subjected to inertia and gyroscopic forces resulting in extremely high angular and radial misalignments. Because of the high misalignment levels, compartment seals capable of accommodating angularities and eccentricities are required. Pratt & Whitney and Stein Seal Company selected the segmented circumferential carbon seal as the best candidate to operate at highly misaligned conditions. Initial seal tests established the misalignment limits of the current technology circumferential seal. From these results a more compliant seal configuration was conceived, designed, fabricated, and tested. Further improvements to the design are underway and plans are to conduct a durability test of the next phase configuration. A technical approach is presented, including design modification to a “baseline” seal, carbon grade selection, test rig configuration, test plan and results of analysis of seal testing.



High Misalignment Carbon Seals

Program Objective

The use of the reduction gear system as the platform for EVNERT demonstration engines will provide revolutionary improvements in engine performance, weight, size, and noise. Due to high periodic radial and angular misalignments introduced into the gear system, high misalignment seals are required to provide adequate compartment sealing beyond present capability. These seals must also have adequate life.

Current Phase Objective

- Fabricate modified seal housing and retaining hardware, new test seals
- Conduct iterative misalignment tests to verify design improvements
- Conduct durability testing.

November 8-9, 2005

Overall program objective identifies the need for seals capable of periodic high radial and angular misalignment.

The current phase objective are to fabricate a modified seal housing and retaining hardware, conduct iterative misalignment tests, and durability tests.



High Misalignment Carbon Seals

Background

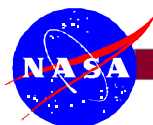
Tomorrow's Engines with Geared Fans will be subjected to extreme conditions such as:

- High angular and radial seal misalignments
Gyroscopic loads - angular misalignment
Sun input gear orbiting - radial/eccentric misalignment
- Higher LPC shaft speed; ~10,000 RPM
- Large Diameter Fan Hub

Seals capable of accommodating high misalignment, high rubbing speeds, low pressure differentials and large diameters must be developed.

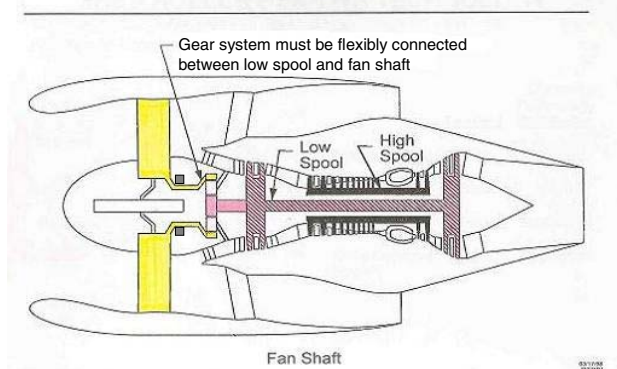
November 8-9, 2005

Background information on principal causes of extreme conditions in Advanced Commercial Engines. Such conditions impose on seals high misalignment, high rubbing speed, large diameters and low pressure differentials.



High Misalignment Carbon Seals

Geared Turbofan Engine (GTF)



Geared Turbo Fan Provides

- 3%-4% TSFC improvement over conventional turbofan engines.
- 30db noise reduction.

November 8-9, 2005

Misalignment seals are located along the flexible shaft between the low spool and fan shaft.



High Misalignment Carbon Seals

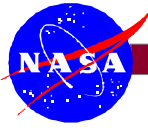
	CURRENT FOCUS					
	FWD. AIR/OIL SEAL	REAR AIR/OIL SEAL	FDGS/LPC COMPARTMENT SEAL			
Required Life (hours)	30,000	30,000	30,000			
Delta P (psi)	<50	<50	40-50			
Surface Speed (ft/s)	33	90	345			
Buffer Air Temperature (deg. F)	350	350	415			
Angular Misalignment (deg)	0.5	0.2	0.1			
Eccentricity (inches)	0.005	0.02	0.005			
Sealing Diameter (inches)	2.95	2.95	11.2			
Type	Segmented/ bellows/ other	Segmented/ other	Segmented/ ring/ other			

Seal Operating Conditions

November 8-9, 2005

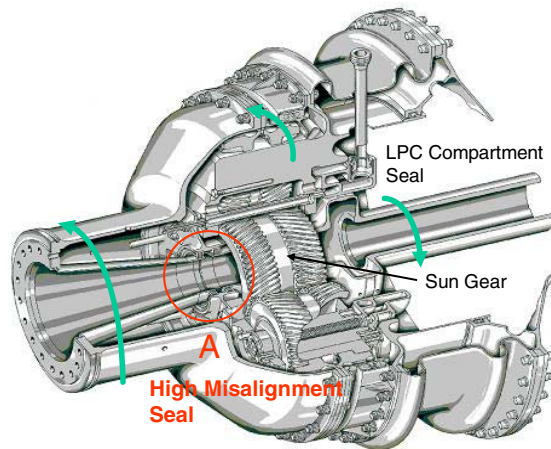
Seal operating conditions (required life, pressure differentials, speeds, misalignment levels and others).

Critical requirements are highlighted.

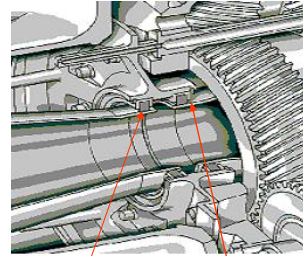


High Misalignment Carbon Seals

Fan Drive Gear System must withstand periodic misalignments as high as 0.105" due to "g" and gyro loads.



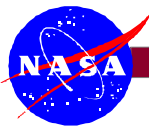
LPT Input Shaft Rotation
CCW from rear



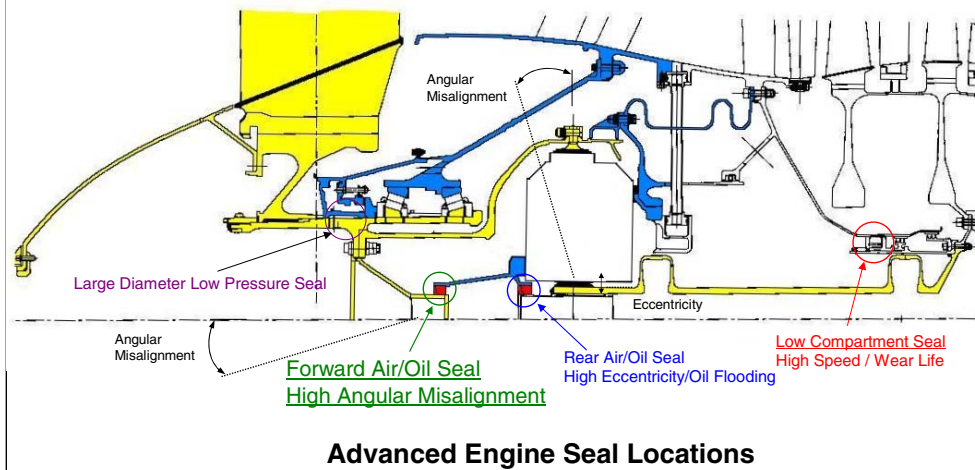
FWD Air/Oil Seal
High Misalignment Seal
Rear Air/Oil Seal
Detail A

November 8-9, 2005

Fan drive gear systems must withstand periodic misalignments as high as 0.105" due to "g" and gyro loads.



High Misalignment Carbon Seals



Advanced Engine Seal Locations

November 8-9, 2005

Seal locations within the forward compartments of the fan drive geared engine. Forward air/oil seal represents the location of the highest source of angular and radial misalignment.



High Misalignment Carbon Seals

Approach - Misalignment Seal Test Rig Program

Stein Seal selected as the seal supplier/tester.

Step 1 – Previous Update

- “Baseline” seal design
- Carbon grade “X” - high strength, low modulus.
- Misalignment increased in steps up to 0.020 in. radial & 0.5° angular

Step 2 – Previous Update

- Misalignment increased in steps up to 0.040 in. radial & 0.5° angular

Step 3 – Previous Update

- Alternate seal with Carbon grade “X” tested
- Misalignment increased in steps up to 0.105 in. radial & 0.5° angular
- Alternate seal with Carbon grade “Y” tested
- Misalignment increased in steps up to 0.105 in. radial & 0.5° angular

Step 4 – Current Phase

- **Modify seal housing and retaining hardware**
- **Fabricate test seals**
- **Conduct three – 20 hour misalignment tests**
- **Conduct two – 100 hour durability tests**

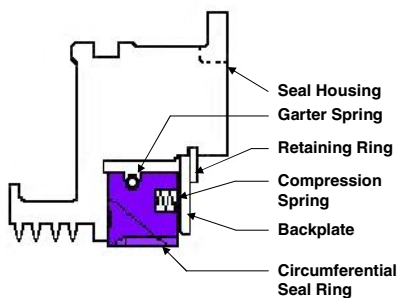
November 8-9, 2005

Technical approach of misalignment seal development program. The current phase represents the fourth main step since starting from “baseline” seal testing.



High Misalignment Carbon Seals

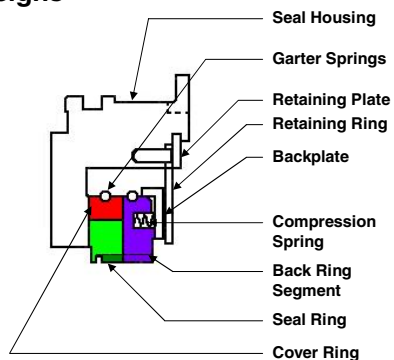
Carbon Seal Designs



1-Piece Segmented Circumferential (Baseline Design)

- 1 Piece design resulted in wear rates that exceeded project limit goals.
- Base material (Carbon X) is suspect to be inappropriate for this application.
- Alternate design & material need to be investigated.

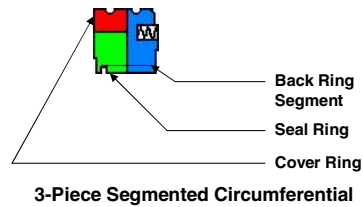
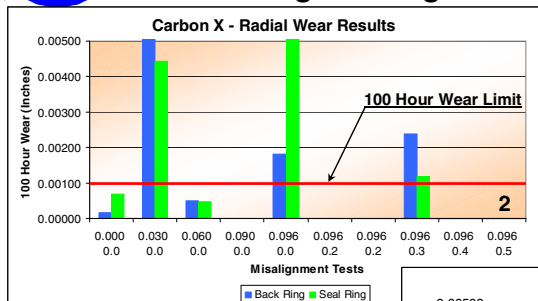
November 8-9, 2005



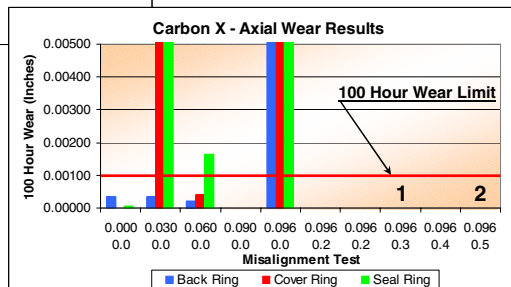
3-Piece Segmented Circumferential (Advanced Design)

Baseline seal was composed of a one-piece 4 segmented seal. Alternate design is composed of a three-piece design, each piece consisting of four segments.

High Misalignment Carbon Seals



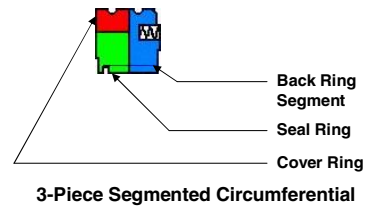
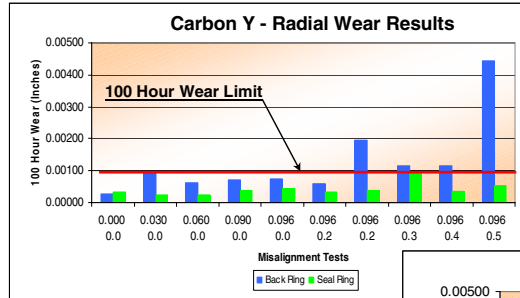
- Carbon X repeatedly exceeds 100 hour wear limit.
1. Excessive coking indicated negative wear.
 2. Test terminated after two attempts resulted in broken seal segments.



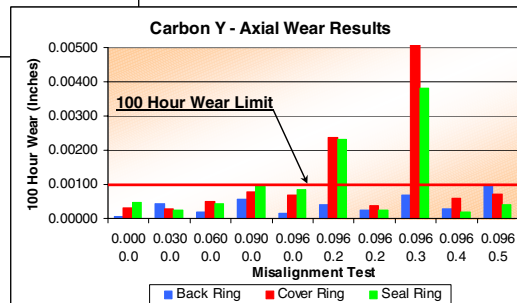
November 8-9, 2005

Carbon X repeatedly exceeds the 100 hour wear limit goal and testing was terminated after multiple failures.

High Misalignment Carbon Seals

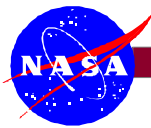


- All components using Carbon Y meets the 100 hour wear limit in Radial misalignment tests.
- Carbon Y components exceed 100 hour wear limit in axial misalignment tests. Mounting hardware damage identified.



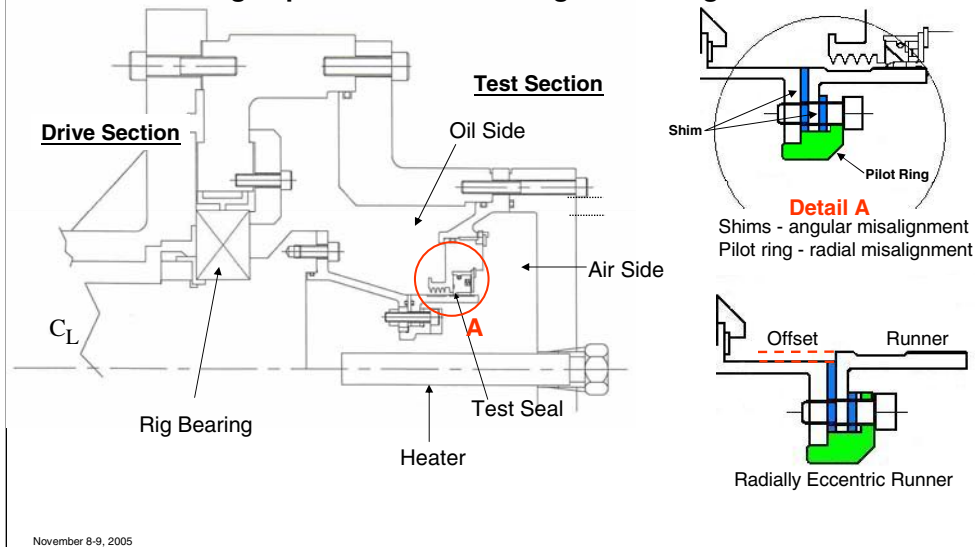
November 8-9, 2005

Carbon Y meets the 100 hour wear limit under purely radial misalignment conditions. Seal retaining hardware suffered fatigue and failure during combination radial & angular misalignment tests. These failures are to be investigated at the potential reasons for the 100 hour wear limit to be exceeded.

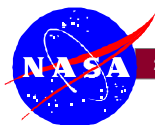


High Misalignment Carbon Seals

Seal Rig Imposes Radial and Angular Misalignment



Seal test rig schematics used to impose radial and angular misalignment. Shims are used to impose angular misalignment and pilot rings are used to impose radial misalignment.



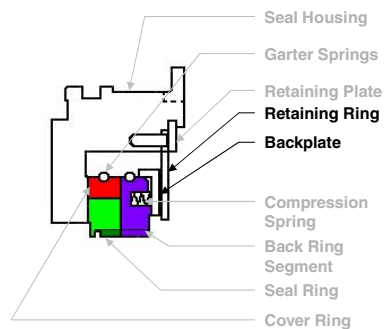
High Misalignment Carbon Seals



Retaining Ring



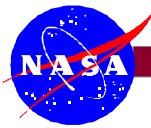
Backplate



Backplate tang steadily wearing into slot of Retaining Ring. Current Seal Housing prohibited design change to increase Retaining Ring to the full thickness of the tang.

November 8-9, 2005

Photos of seal retaining hardware show the wear the occurred during misalignment testing.



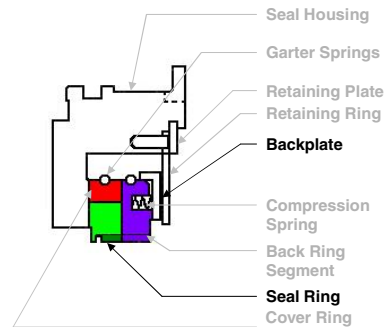
High Misalignment Carbon Seals



Seal Ring wear during test phase of advanced design misalignment tests



Backplate failure during test phase of advanced design misalignment tests

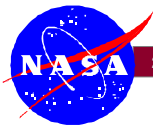


Backplate Key steadily wore into slot of Back Ring and Seal Ring. Modification increased the number of Keys from one to two.

Backplate stress crack identified after test with the largest combination of Radial and Angular misalignment. Modification increased the corner radii at the keys.

November 8-9, 2005

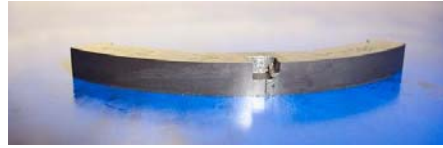
Photos of seal and associated retaining hardware show the wear and stress fracture that occurred during misalignment testing.



High Misalignment Carbon Seals



Backplate Tab Failure



Seal Ring Notch Wear



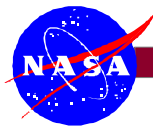
Back Ring Tab Failure



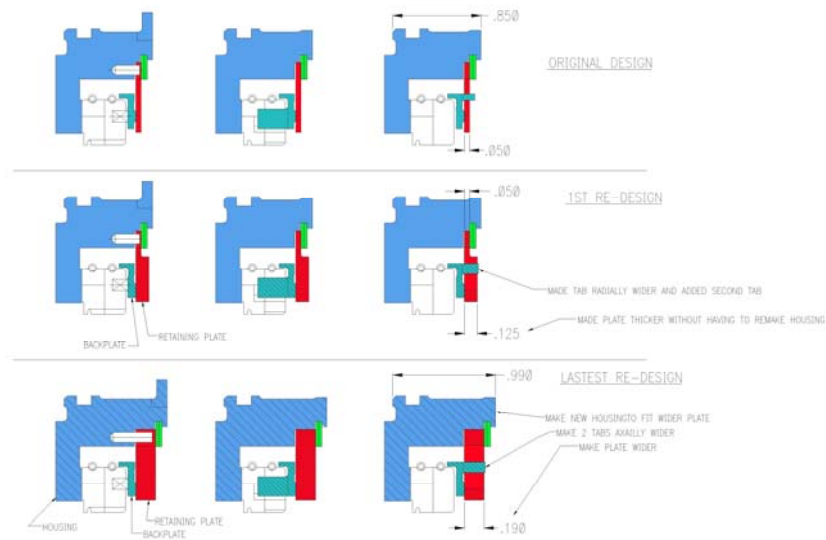
Seal Assembly

November 8-9, 2005

Photos of the seal assembly and signs of wear that occurred during misalignment testing.

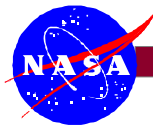


High Misalignment Carbon Seals



November 8-9, 2005

Sections through the test seal illustrate the original design, modifications made during the phase 3 test program and the latest re-design for the current tests phase.



High Misalignment Carbon Seals

Conclusions

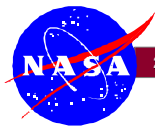
- The baseline design does not meet wear requirements based on Phase II test results and should not be further developed.
- The optimized three-piece carbon design is a significant improvement over the baseline seal.
- The Carbon Y material appears to offer more consistent results and improved wear performance than the baseline Carbon X material.
- Seal retaining hardware on the 3-piece design worn in several instances and may explain carbon wear rates that were greater than goal.

Recommendations - Awaiting test program results

November 8-9, 2005

Conclusions identify that baseline seal design should not be further developed. Also the 3-piece design is a significant improvement over the baseline design. Carbon Y material appears to offer improved wear results from that of Carbon X. Further work is needed to improved the seal retaining hardware.

Recommendations are pending the results of the current test phase results.



High Misalignment Carbon Seals

Plans for Next Year & Beyond

- 2006** Oil windback design
EVNERT demo engine hardware
- 2007** Oil windback tests
EVNERT demo engine tests

November 8-9, 2005

Plans for continuation include windback design and testing.